

IN THE CLAIMS

What is claimed is:

1. A method for making a semiconductor device comprising:
forming a metal oxide layer on a substrate;
converting at least part of the metal oxide layer to a metal layer; and
oxidizing the metal layer to generate a metal oxide high-k gate dielectric layer.
2. The method of claim 1 wherein the metal oxide layer is formed by atomic layer chemical vapor deposition, is between about 5 angstroms and about 40 angstroms thick, and comprises a material selected from the group consisting of hafnium oxide, hafnium silicon oxide, lanthanum oxide, zirconium oxide, zirconium silicon oxide, titanium oxide, tantalum oxide, barium strontium titanium oxide, barium titanium oxide, strontium titanium oxide, yttrium oxide, aluminum oxide, and lead scandium tantalum oxide.
3. The method of claim 2 further comprising forming a gate electrode on the metal oxide high-k gate dielectric layer and wherein the metal oxide high-k gate dielectric layer comprises a material selected from the group consisting of hafnium oxide, zirconium oxide, titanium oxide, and aluminum oxide.
4. The method of claim 3 wherein the gate electrode comprises polysilicon.
5. The method of claim 3 wherein the gate electrode is a metal gate electrode.
6. The method of claim 1 wherein at least part of the metal oxide layer is converted to a metal layer by exposing the metal oxide layer to hydrogen.
7. The method of claim 6 wherein at least part of the metal oxide layer is converted to a metal layer by exposing the metal oxide layer to a hydrogen based plasma.
8. The method of claim 6 wherein at least part of the metal oxide layer is converted to a metal layer by exposing the metal oxide layer to a hydrogen containing gas.

9. The method of claim 1 wherein the metal layer is oxidized to generate a metal oxide high-k gate dielectric layer by exposing the metal layer to an oxidizing agent.

10. The method of claim 9 wherein the oxidizing agent is a solution that comprises a compound selected from the group consisting of hydrogen peroxide, an organic peroxide, and ozone.

11. The method of claim 9 wherein the oxidizing agent is a gas that contains oxygen.

12. A method for making a semiconductor device comprising:

forming a metal oxide layer on a substrate, the metal oxide layer comprising halide impurities and a material selected from the group consisting of hafnium oxide, zirconium oxide, titanium oxide, and aluminum oxide;

reducing at least part of the metal oxide layer to a metal layer by exposing the metal oxide layer to hydrogen;

oxidizing the metal layer to generate a metal oxide high-k gate dielectric layer; and
forming a polysilicon based gate electrode on the metal oxide high-k gate dielectric layer.

13. The method of claim 12 wherein at least part of the metal oxide layer is reduced to a metal layer by exposing the metal oxide layer to a hydrogen containing gas.

14. The method of claim 12 wherein the metal layer is oxidized to generate a metal oxide high-k gate dielectric layer by exposing the metal layer to a solution that contains a peroxide.

15. The method of claim 12 wherein the metal layer is oxidized to generate a metal oxide high-k gate dielectric layer by exposing the metal layer to a gas that contains oxygen.

16. The method of claim 12 wherein the amount of halide impurities included in the metal oxide high-k gate dielectric layer is less than about twenty percent of the amount of halide impurities included in the metal oxide layer, and the amount of oxygen included in

the metal oxide high-k gate dielectric layer exceeds the amount of oxygen included in the metal oxide layer.

17. The method of claim 12 wherein no oxidation occurs on the substrate, when the metal layer is oxidized to generate a metal oxide high-k gate dielectric layer.

18. A method for making a semiconductor device comprising:

forming a metal oxide layer on a substrate, the metal oxide layer comprising halide impurities and a material selected from the group consisting of hafnium oxide, zirconium oxide, titanium oxide, and aluminum oxide;

reducing substantially all of the metal oxide layer to a metal layer by exposing the metal oxide layer to a hydrogen containing gas;

oxidizing the metal layer to generate a metal oxide high-k gate dielectric layer by exposing the metal layer to a solution that comprises a compound selected from the group consisting of hydrogen peroxide, an organic peroxide, and ozone or by exposing the metal layer to a gas that contains oxygen; and

forming a polysilicon based gate electrode on the metal oxide high-k gate dielectric layer;

wherein the amount of halide impurities included in the metal oxide high-k gate dielectric layer is substantially less than the amount of halide impurities included in the metal oxide layer, and the amount of oxygen included in the metal oxide high-k gate dielectric layer significantly exceeds the amount of oxygen included in the metal oxide layer.

19. The method of claim 18 wherein an insignificant amount of oxidation occurs on the substrate, when the metal layer is oxidized to generate a metal oxide high-k gate dielectric layer.

20. The method of claim 19 wherein less than about 10 angstroms of oxide grows on the substrate, when the metal layer is oxidized to generate a metal oxide high-k gate dielectric layer.